AIRBLAST EQUIVALENT WEIGHTS OF VARIOUS EXPLOSIVE CHARGE SHAPES FOR TESTING STRUCTURES

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ABSTRACT

The testing of various security-related and civilian protective structures is often done with explosive charges having cylindrical and other shapes. At long ranges, the characteristics of the blast wave are hardly affected by a complex charge configuration. However, at scaled distances between the charge and test structures, which are less than about 7 m/Kg$^{1/3}$, there exists the phenomenon of blast wave enhancement relative to the more conventional hemispherical or spherical charge shapes. This effect can be put to advantage using the airblast analysis tool of an Equivalent Weight concept. Relatively large Equivalent Weight factors based on actual test data are presented thus providing a useful engineering tool to the Explosion Testing designer.

CV

Mr. Swisdak is a Senior Scientist in the Explosives Event Modeling and Testing Group at APT Research, Inc, headquartered in Huntsville, AL. He recently retired from the Department of Defense after 45 years of service. His specialties include airblast, explosion-produced debris, and its effect on explosive-safety quantity-distance. He is the author or co-author of over 145 technical publications in these fields. He holds a Master of Science degree in Physics from the University of Florida.

Mr. Sadwin, in the field of Explosives and Explosions since 1959, has been an independent Engineering Consultant in this specialty since 1991. He and his team have conducted numerous instrumented full scale explosion tests on structures designed to resist blast. In addition, he has developed a unique graduate level course at the Ben Gurion University entitled "Energetic Explosive Materials". His R&D work has appeared in the form of over 200 Engineering Reports and professional papers.

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14. ABSTRACT
The testing of various security-related and civilian protective structures is often done with explosive charges having cylindrical and other shapes. At long ranges, the characteristics of the blast wave are hardly affected by a complex charge configuration. However, at scaled distances between the charge and test structures, which are less than about 7 m/Kg1/3, there exists the phenomenon of blast wave enhancement relative to the more conventional hemispherical or spherical charge shapes. This effect can be put to advantage using the airblast analysis tool of an Equivalent Weight concept. Relatively large Equivalent Weight factors based on actual test data are presented thus providing a useful engineering tool to the Explosion Testing designer.

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OBJECTIVE

During the full scale testing of targets or structures designed to resist airblast, cylindrical charges, often of cast TNT, are frequently used since they are more easily fabricated than spherical or hemispherical charges. The cylindrical shape, although azimuthally symmetrical, can strongly influence the airblast performance of both peak pressure and positive impulse, at close ranges. In fact, due to the unique behavior of the airblast produced by cylindrical detonations, both enhanced and degraded performance relative to that of spheres or hemispheres is possible.

Cylindrical charge airblast performance information is presented in Reference 1 in graphical form. In this reference, data are presented for various length to diameter (L/D) ratios from vertical, bottom end-initiated cylinders detonated in free-air and from surface burst, top-initiated cylinders. The ordinate parameter of the referenced graphs is the ratio of the Peak Pressure generated from cylinders to that from spherical charges. The abscissa parameter is the scaled range.

The test designer who plans to utilize cylindrical charges for generating explosive loading on targets or test structures needs a convenient and easily applied tool in order to dictate the distance of the structure from the explosive charge where the desired airblast exposure is expected.

METHODOLOGY

We present the use of the Equivalent Weight (EW) method of analysis in order to represent the behavior of cylindrical explosive charges of various values of L/D. The Equivalent Weight Concept itself is described in more detail in Reference 2. An earlier example of the use of this technique was presented in Reference 3 for a cylinder with an L/D of 6/1detonated in free air. In Reference 4, both Pressure and Impulse Equivalent Weights were examined as well.

When determining the explosive loading on a target or test structure, the first step is to define the Peak Pressure and Positive Impulse values that are desired. Once these are known, the charge shape, weight, and location can be computed. Three charge shapes will be considered: hemispherical, spherical and cylindrical. Three aspect (L/D) ratios will be examined for the cylindrical charges: 1/1, 3/1, and 4/1. Since large scale testing usually involves structures that are placed on the ground surface, we discuss only the data from surface burst events.

For hemispherical charges, either Reference 5 or the DDESB Blast Effects Computer[6] can be used to generate pressure versus scaled distance curves. Reference 1 can be used to generate similar pressure information for spheres and cylinders detonated on the surface. Impulse information for 3/1 cylinders can be found in Reference 7.

Figure 1 compares the peak pressure for spheres and hemispheres detonated on the surface, while Figure 2 compares the peak pressure produced by three aspect ratio cylinders (1/1, 3/1 and 4/1) under similar conditions. Figure 3 compares the scaled positive impulse produced by spheres, hemispheres, and 3/1 cylinders detonated on the surface.

The major emphasis of the paper will be on peak pressure-related topics, with a limited discussion of impulse effects. This is because there is significantly more pressure-related information than cylindrical impulse data in the literature.

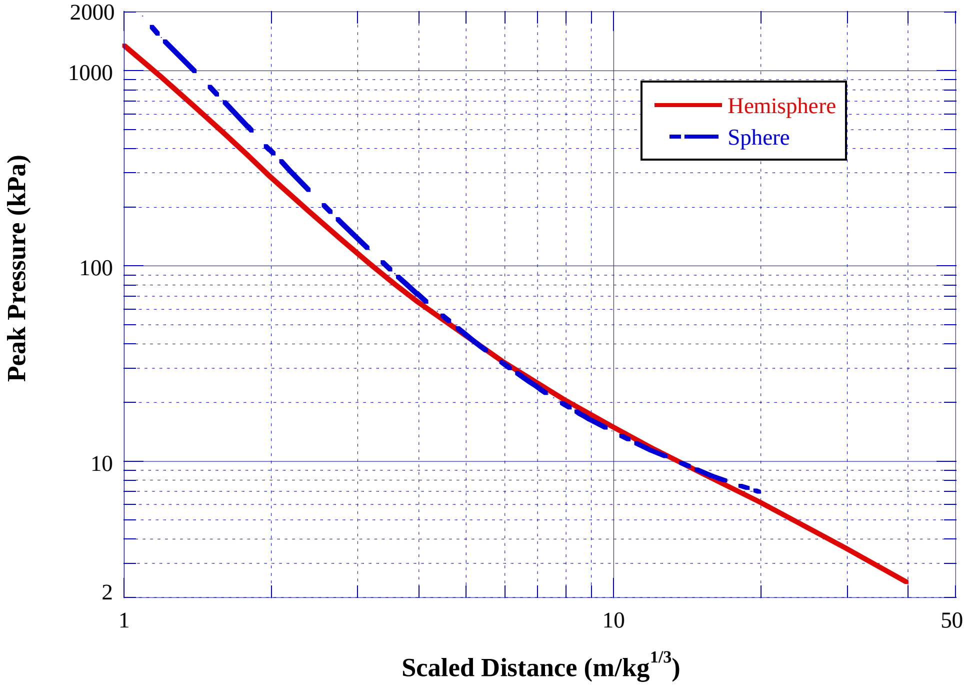

FIGURE 1. Pressure vs. Scaled Distance for Hemispheres and Spheres

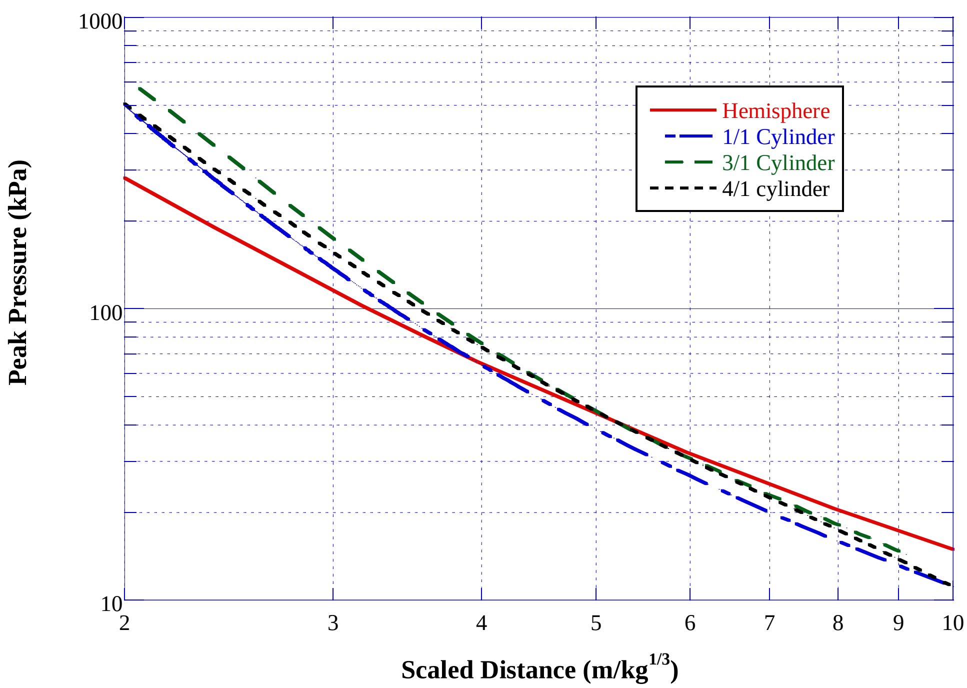

FIGURE 2. Pressure vs. Scaled Distance for Hemispheres and Cylinders

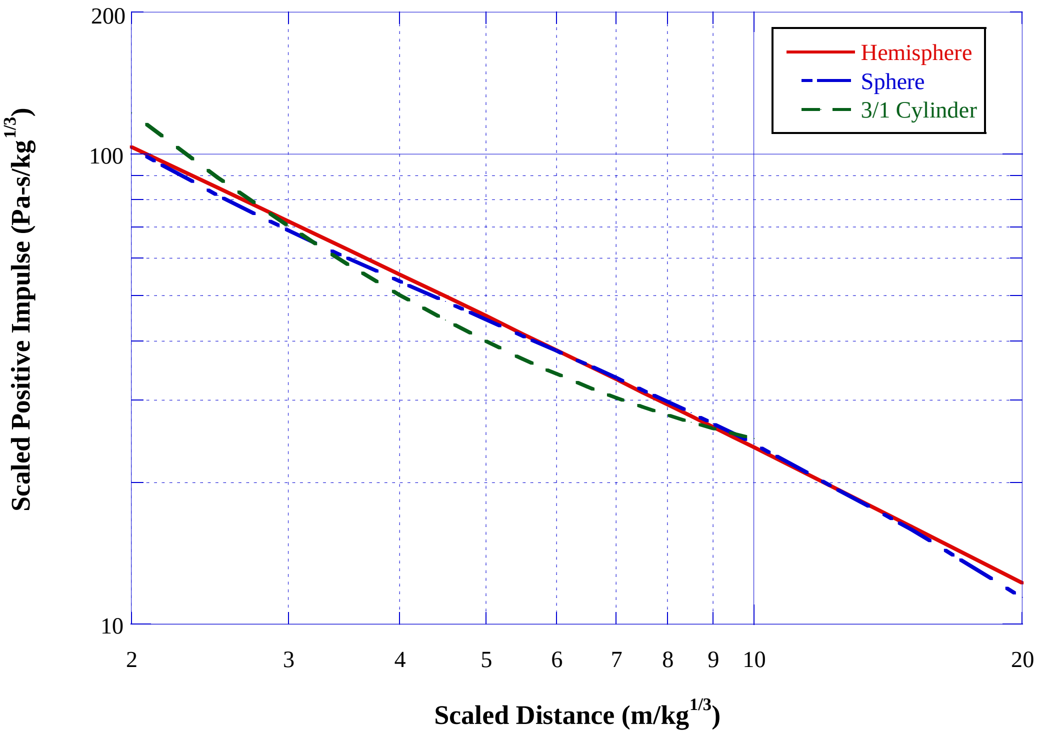

FIGURE 3. Scaled Impulse vs. Scaled Distance for Hemispheres, Spheres and Cylinders

PRESSURE RESULTS

Examining Figure 1, we see that relative to the hemispherical airblast, the sphere produces higher airblast at pressures above about 50 kPa. Below this value, the spherical airblast falls below the hemispherical airblast, until a pressure level of about 10 kPa is reached.

Using the EW concept, the variation of the spherical charge output relative to a hemispherical charge can be calculated. This is shown in Figure 4. At about the 280 kPa level, the EW of spheres is about 1.5 compared to hemispheres. The EW falls below 1.0 at about 50 kPa. Although not shown in the Figure, the EW again rises above 1 below about 10 kPa.

Examining the cylindrical airblast shown in Figure 2, we see that relative to the hemispherical airblast, the1/1 cylinder produces higher pressures above about 75 kPa, while the 3/1 and 4/1 cylinders produces higher pressures above about 40 kPa. Below these values, the cylindrical pressure falls and remains below that of the hemisphere.

Again, using the EW concept, the variation of the cylindrical charge output relative to a hemispherical charge can be calculated. These are shown in Figure 5. The airblast from the 1/1 cylinder is above that of a hemisphere at pressures above 75 kPa; the 3/1 and 4/1 cylinders are above a hemisphere at pressures above about 40 kPa. Below these pressure levels, the pressure equivalence falls below 1 and is less than that of a hemisphere.

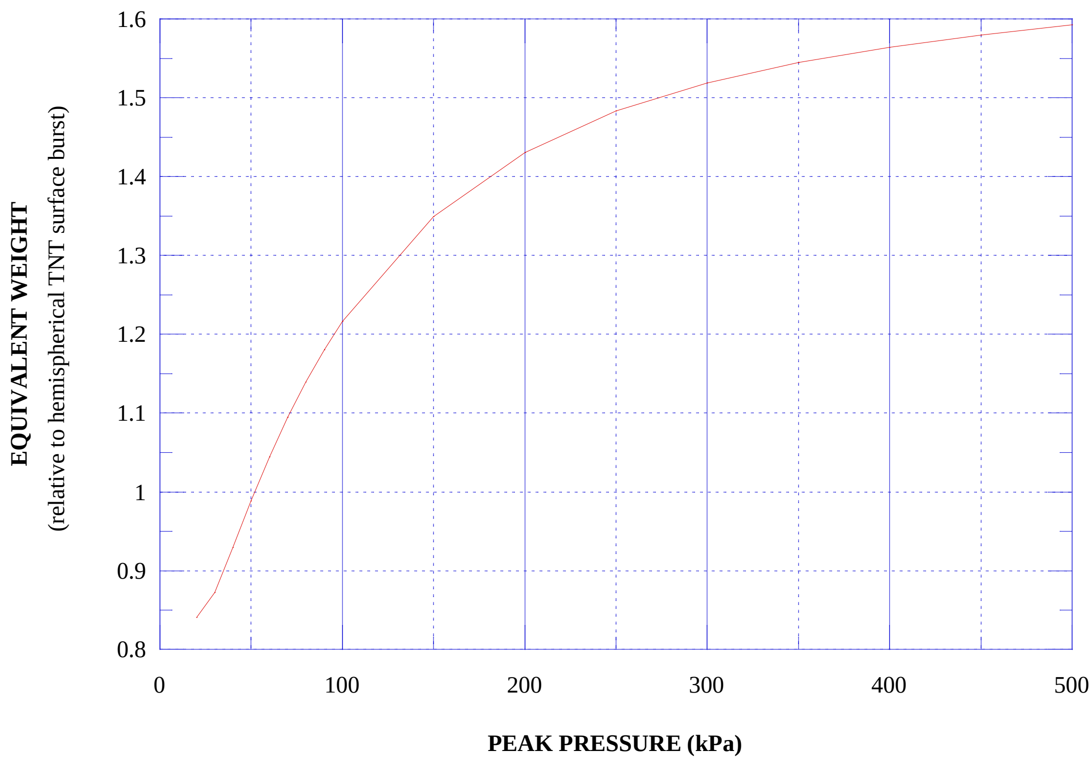

FIGURE 4. Pressure Equivalent Weight vs. Peak Pressure of Surface Burst Spheres

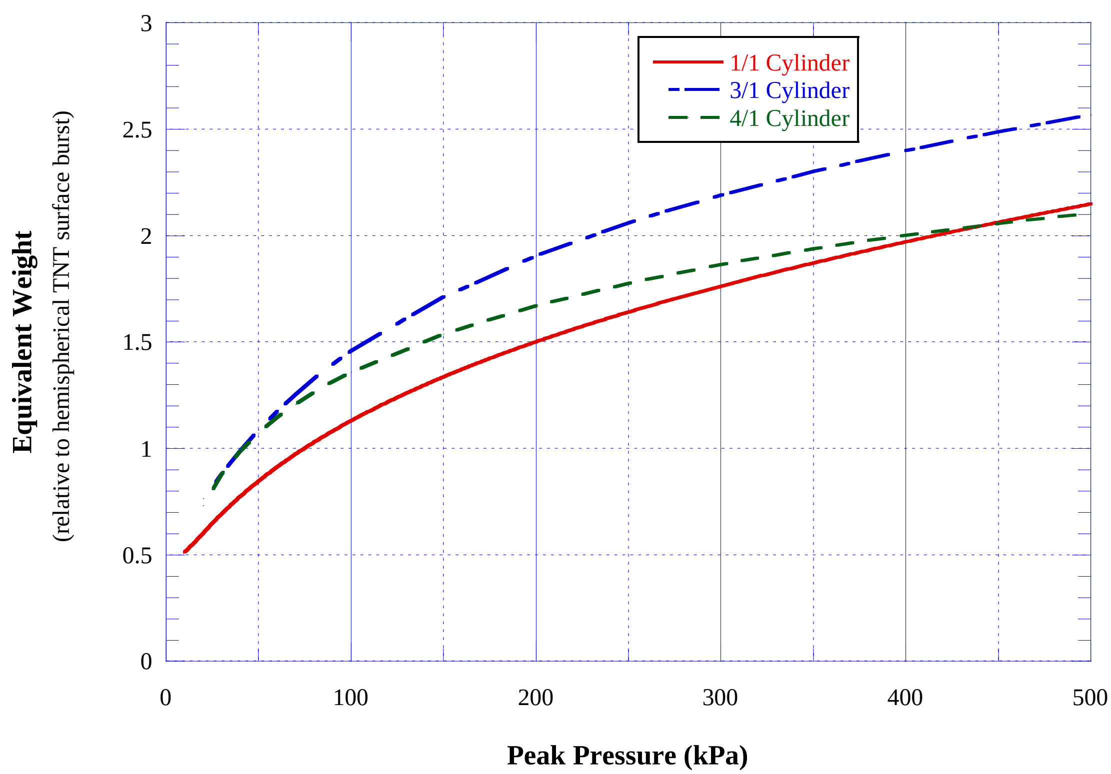

FIGURE 5. Pressure Equivalent Weight vs. Peak Pressure of Surface Burst Cylinders

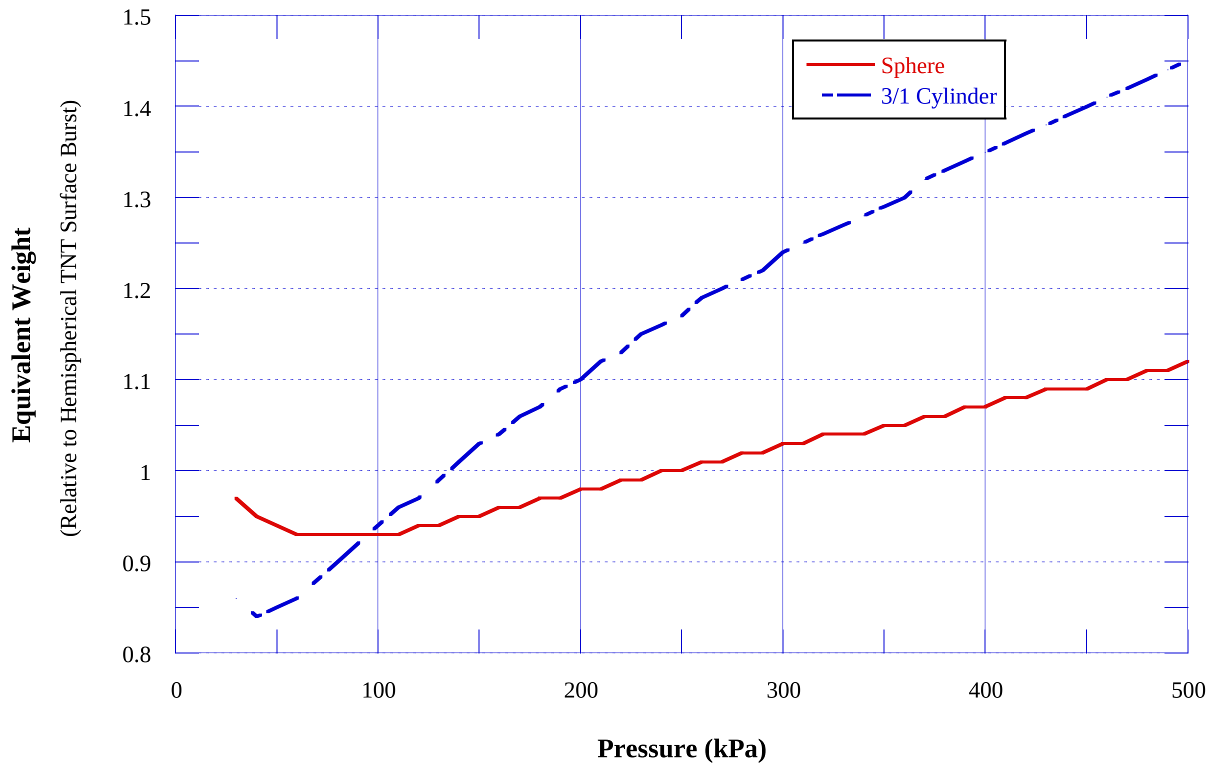

FIGURE 6. Impulse Equivalent Weight vs. Peak Pressure of Surface Burst Spheres and Cylinders

Examining the impulse data shown in Figure 3, we see that relative to the hemisphere the sphere produces nearly identical impulses, while the 3/1 cylinder produces higher impulses above about 150 kPa. Again, using the EW concept, the variation of the output relative to a hemispherical charge can be calculated. These are shown in Figure 6.

APPLICATION

Suppose that a test is being planned that requires a full-scale structure to be loaded with a pressure level of 350 kPa. If we were to use a hemispherical charge, it would have to be placed at a scaled distance of 1.82 m/kg$^{1/3}$. A spherical charge would need to be placed at 2.10 m/kg$^{1/3}$. Depending on the L/D ratio of the cylinder, these would need to be placed at the following distances: 2.22 m/kg$^{1/3}$ (1/1), 2.40 m/kg$^{1/3}$ (3/1), or 2.27 m/kg$^{1/3}$ (4/1).

Let us assume that the charge shape is hemispherical and the weight of this charge shape is W. Examining Figures 3 and 4, we see that this same pressure level can be achieved with a much smaller charge weight if other charge shapes are considered. These are shown in Table 1.

Table 1. Effect of Charge Shape on Required Charge Weight

Charge Shape	350 kPa Charge Weight		80 kPa Charge Weight	
Hemisphere	W	W	W	W
Sphere	W/1.54	0.65*W	W/1.14	0.88*W
1/1 Cylinder	W/1.87	0.53*W	W/1.04	0.96*W
3/1 Cylinder	W/2.30	0.43*W	W/1.33	0.75*W
4/1 Cylinder	W/1.94	0.52*W	W/1.25	0.80*W

As can be seen in Table 1, once a pressure level is selected for an explosive loading test, the choice of the charge shape has the potential of saving test costs by reducing the amount of energetic materials required. For a 350 kPa blast, charge weight reductions of over 50%, compared to a hemispherical charge, are possible. The savings are not as dramatic, however, at other pressure levels. As the required blast loading approaches or falls below 10 kPa, little or no charge weight savings are obtained. Moreover, at these lower pressure levels, a weight penalty may accrue, as the TNT equivalence of these alternate charge shapes falls below a value of 1.

When impulse must also be considered, the reductions are not as dramatic. Because the impulse from spheres is nearly identical to hemispheres, changing to a spherical charge shape would not cause a weight reduction. However, if a 3/1 cylinder is used, the weight could be reduced by W/1.3 and still achieve the same impulse as a hemisphere with a weight of W.

CONCLUSIONS

The EW of cylindrical TNT relative to hemispherical TNT is greater than 1.0 for scaled ranges less than about 4 m/kg$^{1/3}$ for 1/1 cylinders and about 5 m/kg$^{1/3}$ for 3/1 and 4/1 cylinders . Spherical TNT has increasing EW values and is greater than 1.0 for Peak Pressure levels above 35 KPa. We have shown that introducing the charge shape as a variable can lead to significant cost savings.

Many test structures are sensitive to not only the Pressure but also the Positive Phase Impulse imparted to them by the test explosion. Comprehensive Impulse data from cylinders detonated on the surface are, at best, limited in nature, and in many cases not available. The authors know of only limited data on the impulse characteristics of surface burst cylinders.

It is recommended that a comprehensive program of airblast measurements from surface burst cylinders be undertaken to fill-in this void of information.

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Airblast Equivalent Weights of Cylindrical Explosive Charges for Testing Structures

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WHAT IS EQUIVALENT WEIGHT (YIELD)?

- Weight of a standard explosive required to produce a selected blast parameter of equal magnitude to that produced by a unit weight of the event or material in question

EQUIVALENT WEIGHT BASED ON PEAK PRESSURE

SEC

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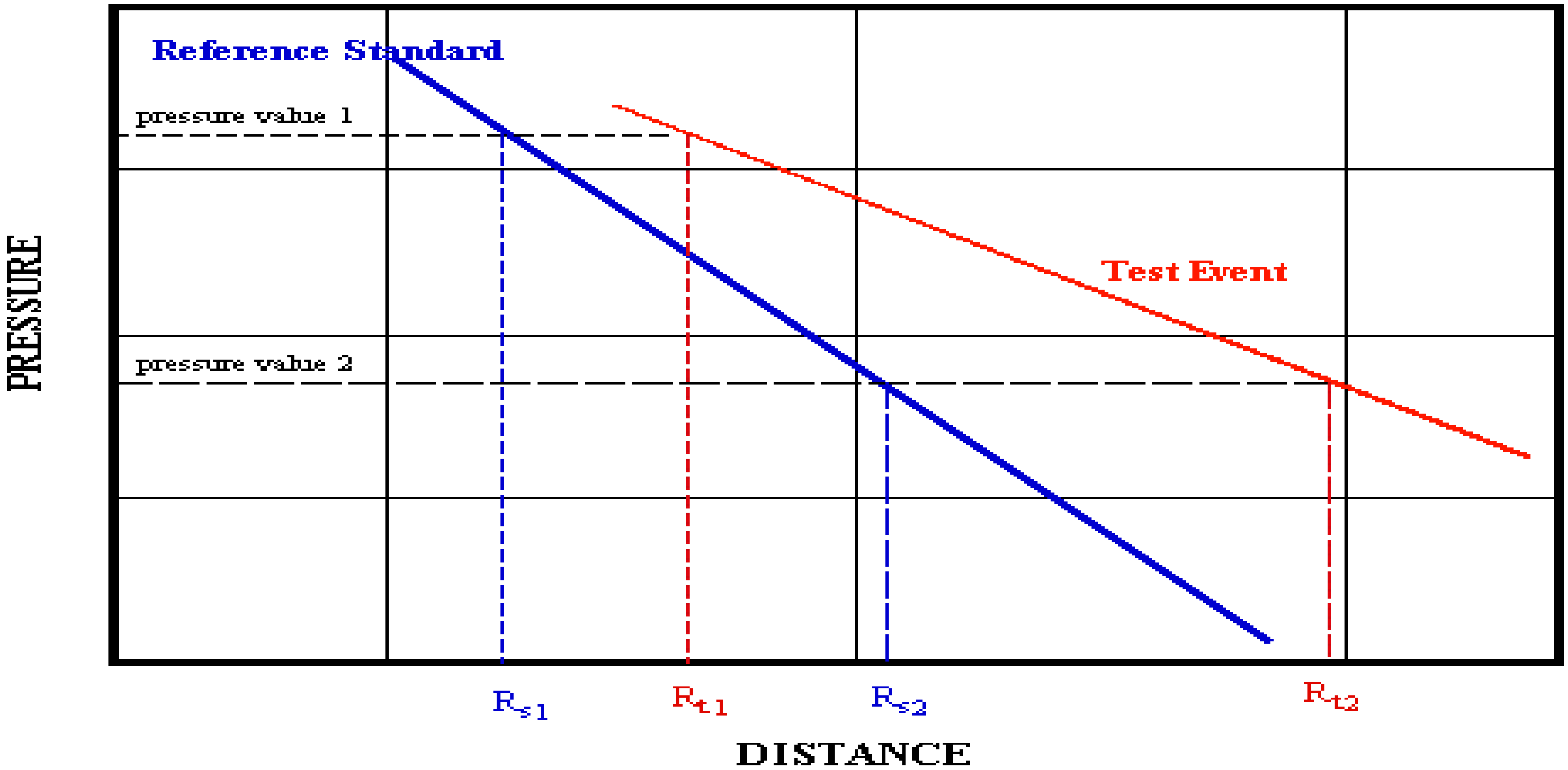
$$Yield = \left(R_{test} / R_{\mathrm{standard}} \right)^{3}_{\mathrm{pressure=constant}} \left(W_{\mathrm{standard}} / W_{test} \right)$$

PRESSURE YIELD



$$Yield\ 1 = \left[\frac{R_{t1}}{R_{s1}}\right]^3 \left[\frac{W_s}{W_t}\right]$$

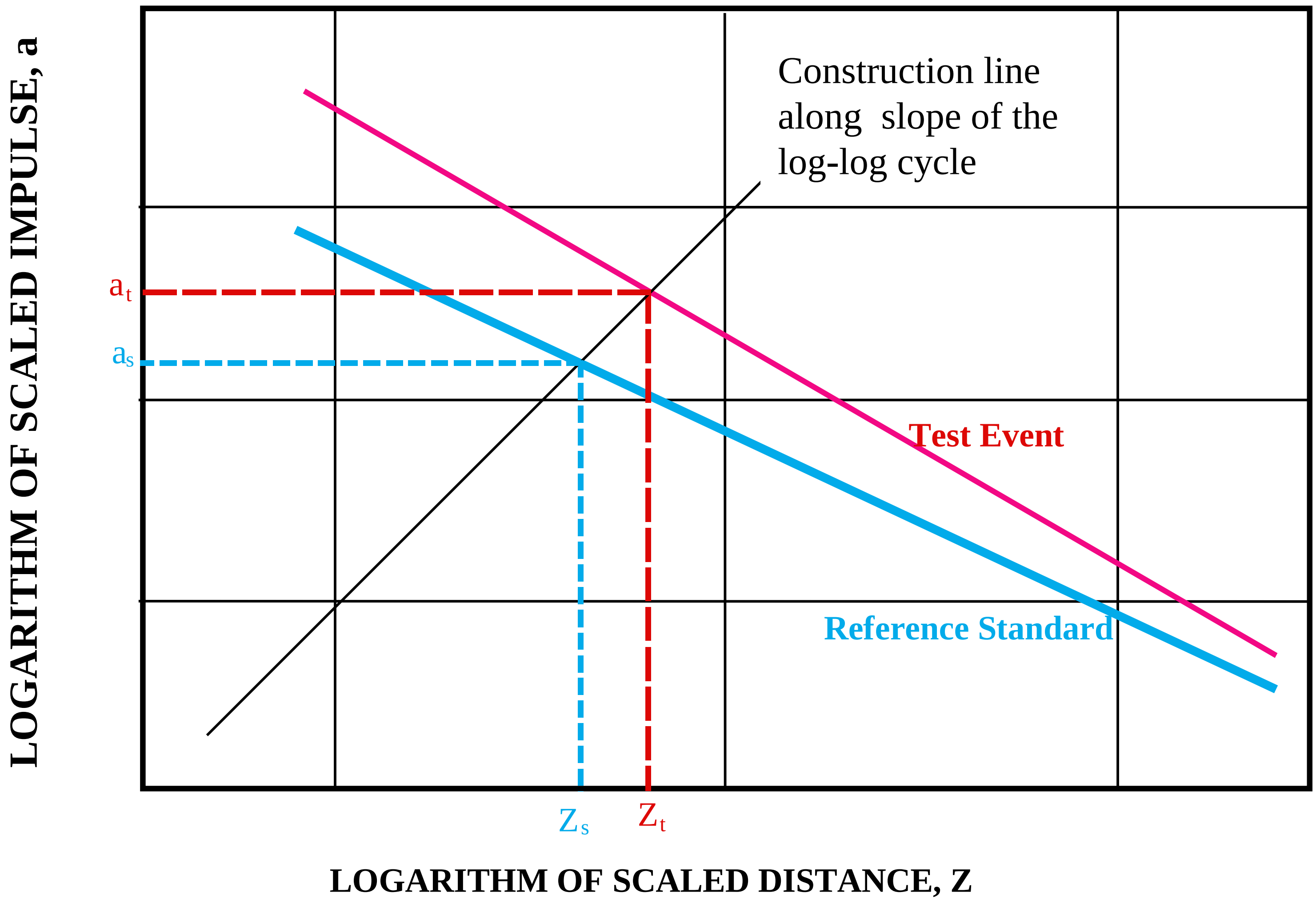
$$Yield\ 2 = \left[\frac{R_{t2}}{R_{s2}}\right]^3 \left[\frac{W_s}{W_t}\right]$$

EQUIVALENT WEIGHT BASED ON IMPULSE

$$Yield = \left(I_{test} \middle/ I_{standard} \right)^3$$

- Note: Ratio is taken along slope lines of the log-log cycles in log-log space

IMPULSE YIELD



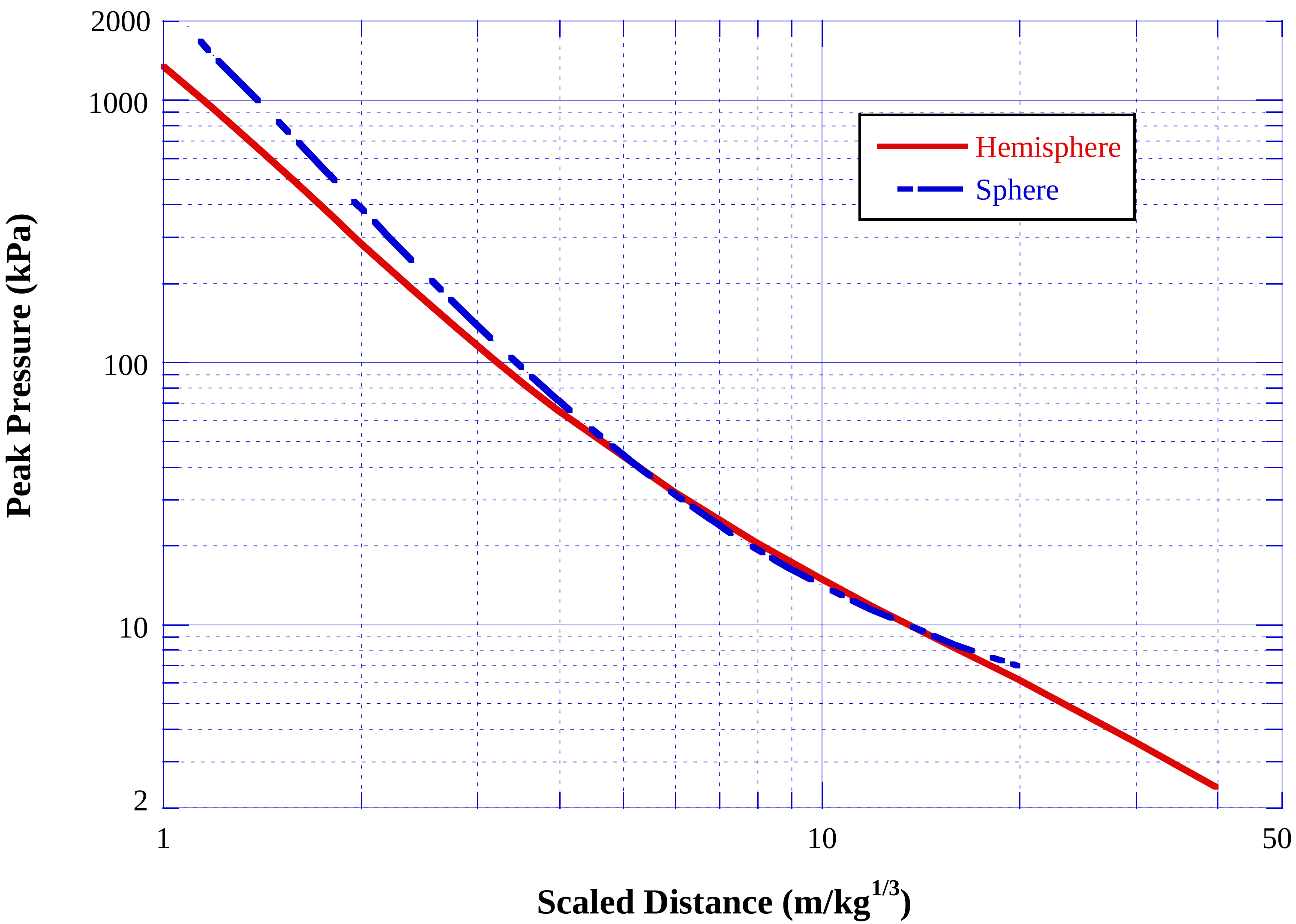
IMPULSE YIELD (continued)

- Scaled Reference Impulse = $a_s = I_s/W_s^{1/3}$
- Scaled Test Impulse = $a_t = I_t/W_t^{1/3}$

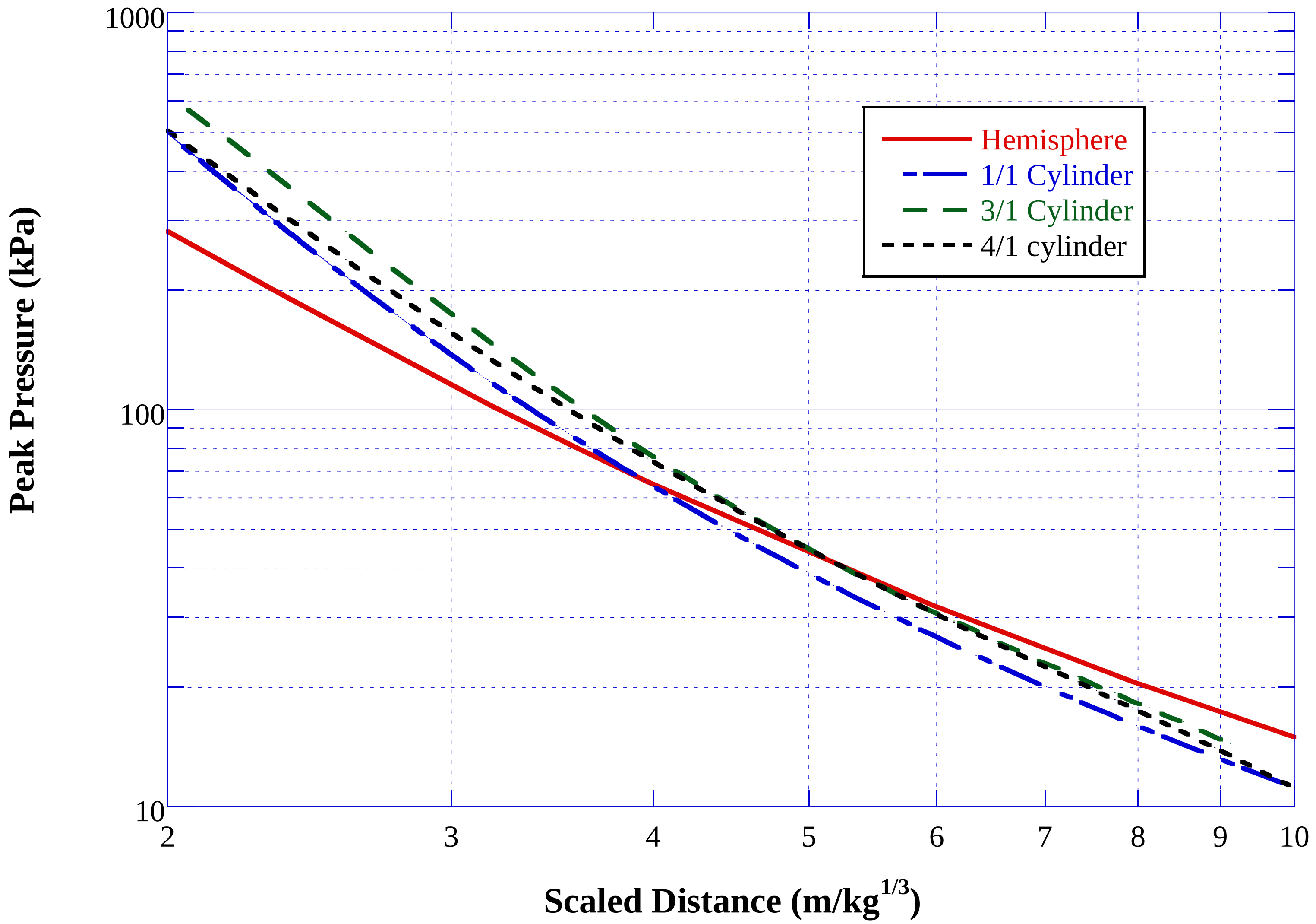
- Scaled Reference Distance = $Z_s = R_s/W_s^{1/3}$
- Scaled Test Distance = $Z_t = R_t/W_t^{1/3}$

- **Yield = $(a_t / a_s)^3$ at points of intersection of construction line with both impulse curves**

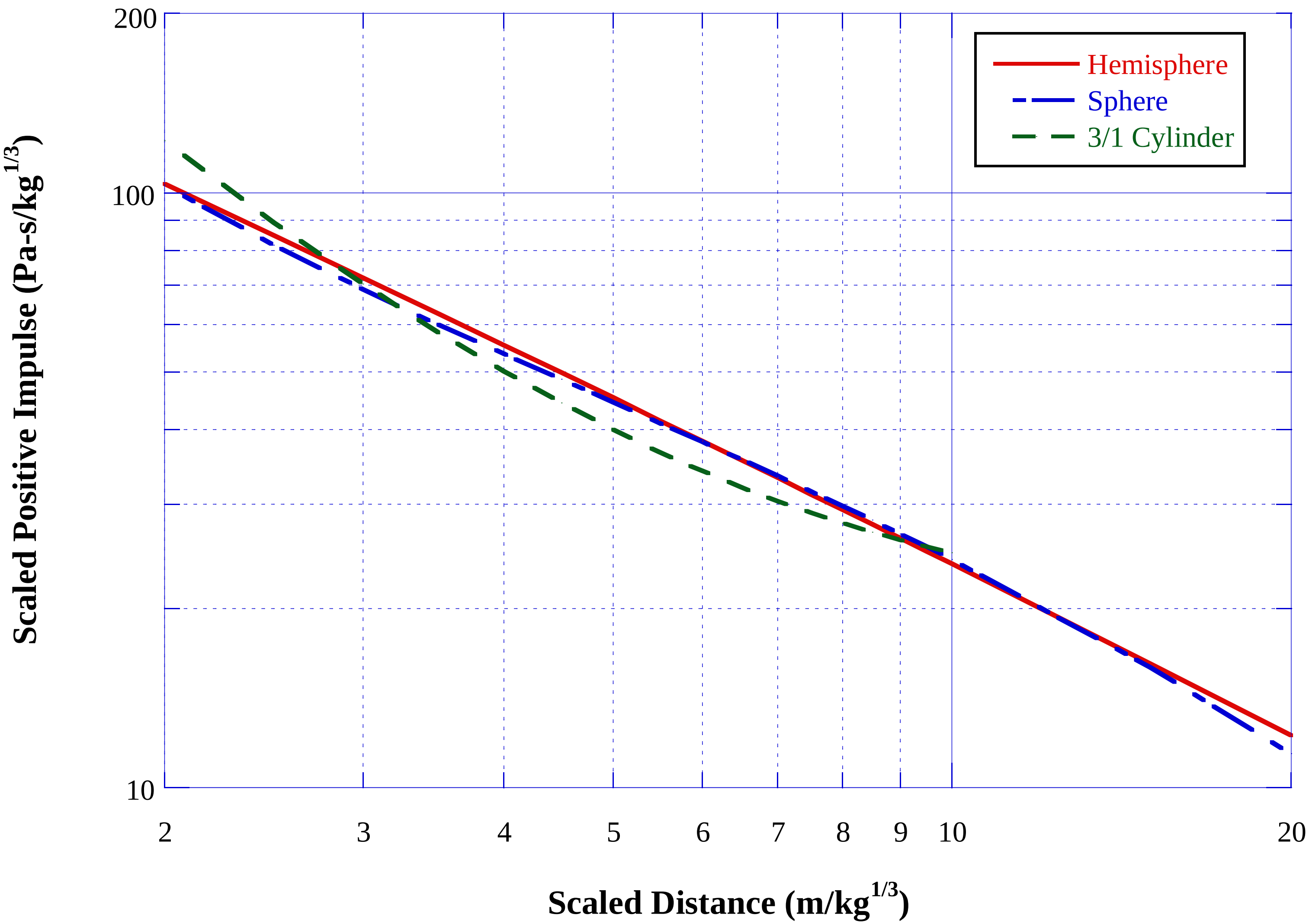
Pressure vs. Scaled Distance
Spheres and Hemispheres



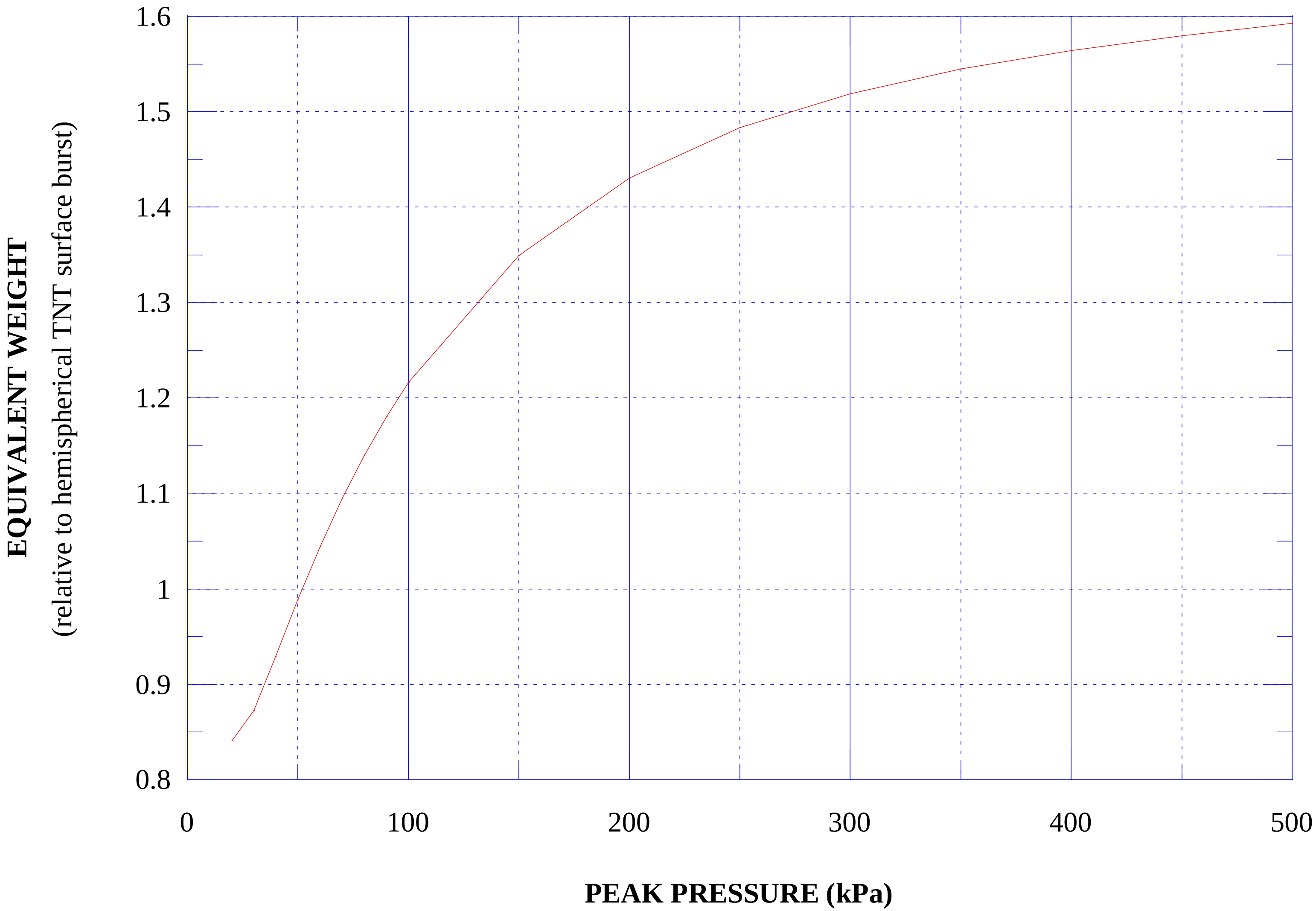
Pressure vs. Scaled Distance Hemispheres and Cylinders



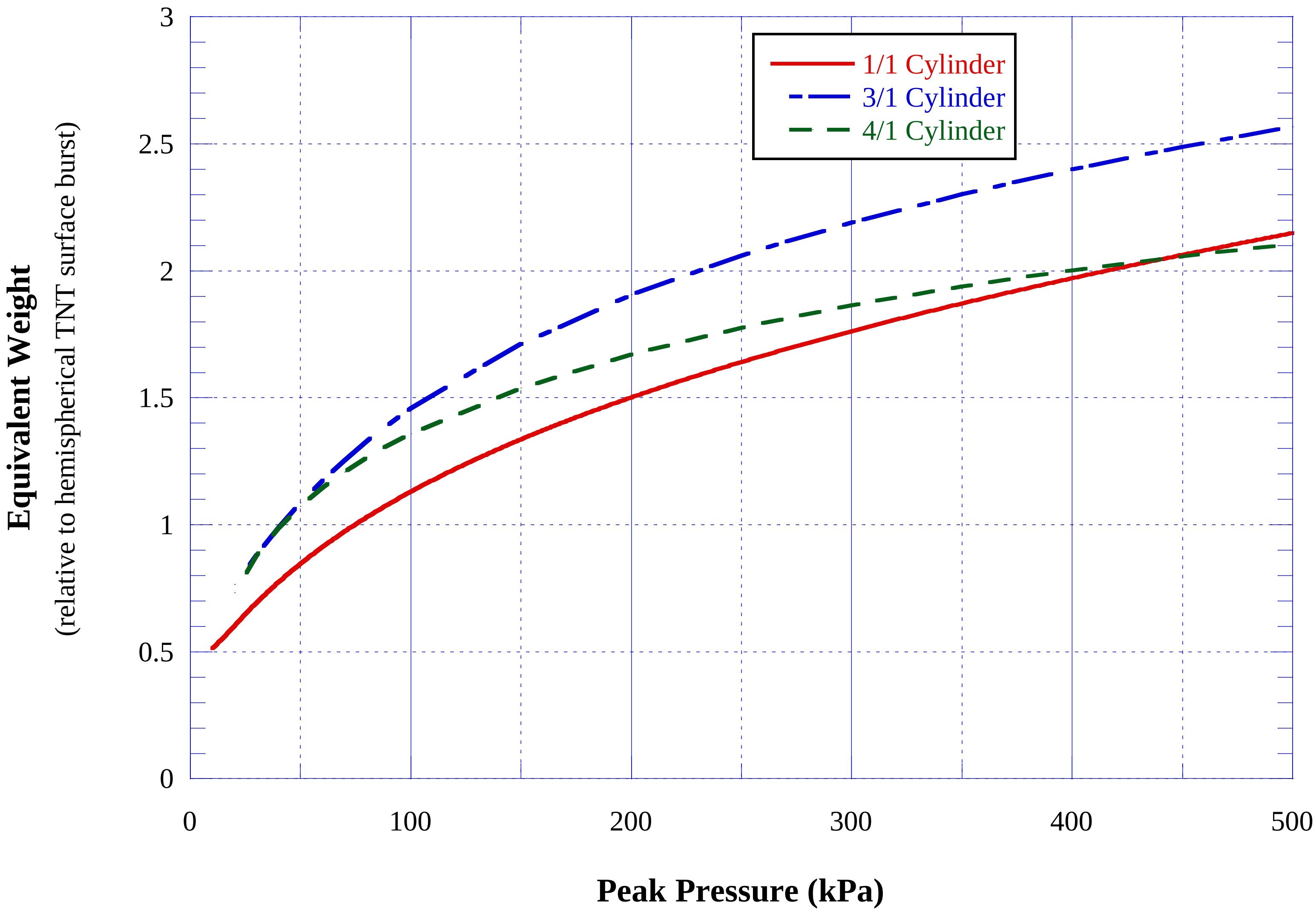
Scaled Impulse vs. Scaled Distance Hemispheres, Spheres, and Cylinders



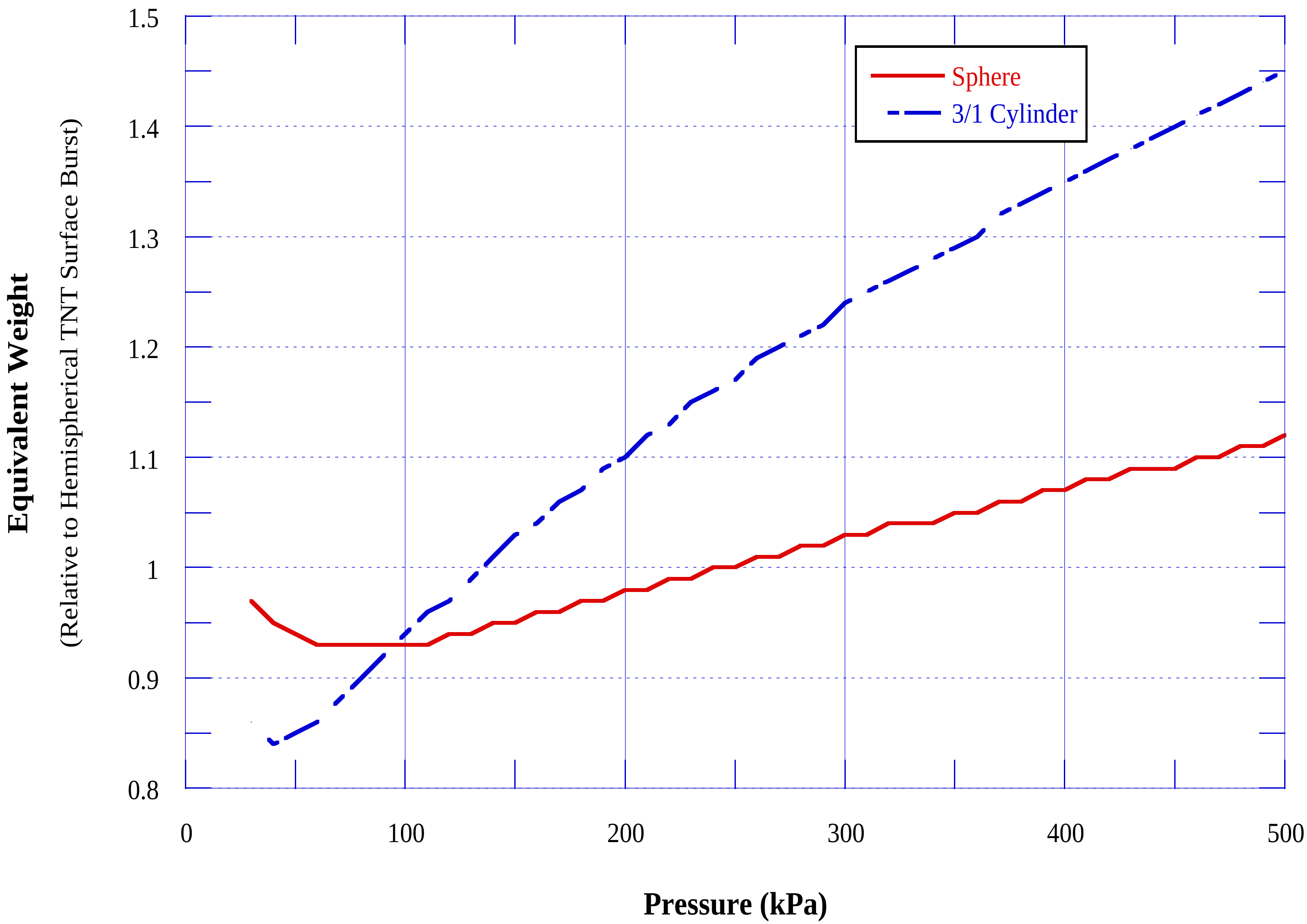
Pressure Equivalent Weight vs. Peak Pressure Surface Burst Spheres



Pressure Equivalent Weight vs. Peak Pressure
Surface Burst Cylinders



Impulse Equivalent Weight vs. Peak Pressure Surface Burst Spheres and Cylinders



Effect of Charge Shape On Required Charge Weight

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